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MAINTAINING THE FERTILITY OF RICE SOILS; A CHEMICAL STUDY.

BY

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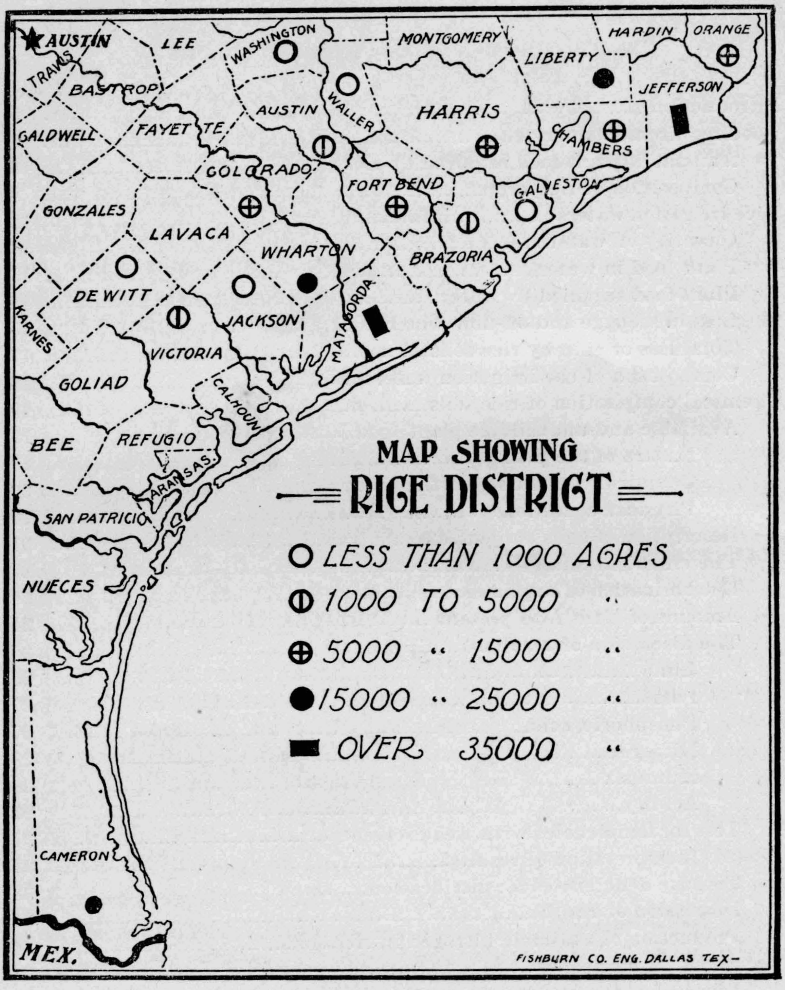


RICE DISTRICT OF TEXAS.

MAINTAINING THE FERTILITY OF RICE SOILS—A CHEMICAL STUDY.

BY G. S. FRAPS.

This bulletin is a study of the plant food in the rice crop, the irrigation waters, and some rice soils, with a view to ascertaining the amount of plant food required by the crop, the amount carried in the irrigation waters, the losses of plant food from the soil, the content of the soils in plant food, and their deficiencies in this respect, if any. On the information thus secured, recommendations for maintaining the fertility of rice soils are made.

The subject is treated in four divisions, as follows:

I. Food requirements of rice.
II. Rice irrigation waters.
III. Some rice soils.
IV. Treatment of rice soils.

INTRODUCTION.

The rice industry of Texas has grown from 2000 acres in 1895 to 234,000 acres in 1904. Lands are under rice culture all the way from Orange to Brownsville.

The accompanying map gives an idea as to the present development of the area. The land is mostly level prairie land, and, perforce, the development takes place where an abundant supply of water can be had. Most of the water at present comes from rivers or bayous, though the area watered by wells is not inconsiderable. A large area is still capable of development.

CULTIVATION OF RICE.

The rice cultivated in Texas is "lowland" rice, that is, it is grown with the soil covered with water. The following is a brief outline of rice culture as practiced here:

Preparation of the Soil.—The soil is ploughed between November and May, as early as possible, and particularly before vegetation starts in the spring. The depth of ploughing is two to four inches. Shallow ploughing is practiced for two reasons. One is that the harvesting machinery sinks to the depth of ploughing, and the difficulty of draft increases with the depth. Another reason advanced is that rice thrives better in compact earth.

Planting.—Planting takes place between February 20th and

June 15th, according to the season, location, and local conditions, such as the number of men at work. Most planters consider April the best month. The amount of seed used is about eighty pounds of Honduras or sixty-five pounds of Japan per acre.

Irrigation and Flooding.—If the ground is dry, the field may be irrigated immediately after planting; otherwise an irrigation may occur later, or not at all, until the time of flooding.

The rice is flooded when it has attained the height of six to ten inches and is sufficiently stooled, which takes place in forty to seventy days. The fields are covered with three to six inches of water, and left covered, as far as possible, until near harvest. If the soil is well shaded by the crop, just enough water to keep the soil saturated will answer, but if the stand of rice is thin the water should be deeper. Unequal depths of water is said to cause the crop to ripen at different times. Salt water is very injurious to rice. Strongly saline water will kill the plants, while it is said the water less salty causes the plant to grow to leaves and produce little grain.

Recent experiments at this station indicate that young plants will endure more salt than older ones.

Harvesting.—About ten days before harvest the leaves are cut and the field drained. The grain rapidly hardens and by the time it is ready to cut the field is sufficiently dry to permit the use of the reaper and binder.

The rice is cut at a height of from ten to twenty inches, unless it is badly lodged or down, when it is necessary to cut as closely as possible. The height of Honduras rice is from three to seven feet, according to conditions, and from one-half to one-sixteenth of the straw is left in the field as stubble. The stubble is burned, or ploughed under. Some planters burn all that weather conditions permit, to avoid ploughing a little deeper to turn the stubble under thoroughly. Others turn all the stubble under. Part of the rice straw is fed; most of it burned, however. The losses of plant food in burning the stubble and straw, or removing the latter, will be discussed fully on another page. (See page 10.)

By-Products of Rice Growing.—The chief by-product in rice growing is the straw. This is, for the most part, burned, though some is ploughed under (as stubble) and a portion is used as roughness for their work stock and cattle by a number of planters, who find it makes a good rough feed. It is characteristic of our present age that every industry should utilize as fully as possible the by-products which it produces, and many an industry finds a large source of profit in by-products, formerly despised and thrown away. We shall expect to find in the future a larger utilization of the thousands of tons of rice straw now burned, either for feeding purposes, bedding, or otherwise. It is certainly worth more for feeding than rice hulls, and I am informed that it is excellent for bedding.

The by-products of rice milling have been discussed by the

Chemical Division of this Experiment Station in Bulletin No. 73. We wish to record here some analyses showing the fertilizing constituents of rice hull ashes. (See Table I.) Rice hull ashes contain little fertilizing ingredients, and are of little value as a fertilizer.

TABLE I.

Pounds of plant food in 100 pounds hull ashes and straw ashes.

	Phosphoric Acid.	Potash.
Hull ashes	1.73	.62
Hull ashes	.21	.80
Hull ashes	.41	.71
Hull ashes*	.82	.93
Hull ashes†	.65	1.58
Average	.76	.93
Straw ashes†	1.00	13.58
Straw ashes†	1.97	14.81

I. FOOD REQUIREMENTS OF RICE.

Plants, as well as animals, require food, though the food required by plants is quite different from that needed by animals. Plants use simple food, and build it up into complex forms for animal food, while animals break down their food into simple forms which can be utilized by plants. There is thus a constant circulation of matter between plants and animals.

The larger part of the material of which plants are composed comes from the air, about 90 per cent of the dry plant coming from this source in the case of rice. The remainder comes from the soil. There are certain food substances in the soil which are absolutely necessary for the life of the plant. If they are withheld, the plant will make a feeble growth from the small store in the seed, and then perish. When soils are naturally productive, they contain an abundance of plant food, in such forms that plants can get it, but as each crop that is removed carries off a certain amount, in time the productiveness of the soil must decrease as the amount of plant food in it diminishes.

Soils may be unproductive because they do not supply enough food to the plants which grow on them, although there are other causes of unproductiveness. If due to the lack of one or more forms of plant food, the crop may be increased by the addition of the necessary substances.

The most important forms of plant food in the soil are nitrogen,

* Louisiana Experiment Station Bulletin No. 77, 1904.
† South Carolina Experiment Station Bulletin No. 59.

phosphoric acid and potash. Whenever a soil is deficient in plant food, as a rule, nitrogen, phosphoric acid or potash, one or more, are needed. Lime, magnesia, sulphuric acid and chlorine are indeed taken from the soil by plants, and are absolutely necessary for their proper growth and development, but it is the common experience that they are present in nearly all soils in sufficient quantities for good crops, while nitrogen, phosphoric acid and potash may not be. Lime is often added to soils, but the purpose is to correct the acidity of the soil, to improve its physical condition, to unlock potash, but not to serve directly as plant food. Sulphuric acid is probably deficient in some soils. We must bear in mind the fact that a part or all of the favorable action of a fertilizer may be due in some cases to the substances associated with the phosphoric acid, nitrogen or potash in it.

It is not out of place to state here that phosphoric acid, potash or nitrogen do not occur as such in the soil, fertilizers or manures, but always in combination with other substances.

AMOUNT OF PLANT FOOD REQUIRED BY RICE.

The amount of plant food required to produce a crop is difficult to determine. An approximate estimate can be made by determining the amount of plant food contained in the different crops, but since plants often take up an excess of one or more elements, an estimate so made is usually high. However, proceeding in this way, valuable data can be obtained, and we will accordingly make such an estimate for rice.

The amount of plant food taken up by rice or any other crop depends upon the composition of the crop, and its amount, both of which will be discussed in the following paragraphs.

Composition of Rice Crop.—The composition of the rice crop varies according to the soil, season, climate and variety. The average composition, which we must of necessity use, will give results which are high for one field, low for another, but correct on an average. The composition of rough rice and rice straw (Honduras) is presented in Table II. Sulphur (as SO_3) is included because there is room to believe that some soils are deficient in sulphur, and part of the beneficial results attributed to phosphates or potash may in these cases be due to the sulphur they carry. This question deserves further study.

TABLE II.

Pounds of Plant Food in 100 Pounds of Rough Rice and Rice Straw.

Ref. No.		Ash.	Phosphoric Acid.	Nitrogen.	Potash.	Sulphur as SO_3.
199	Rough rice............	5.15	.55	1.30	.25	.21
201	Rough rice............	4.01	.29	1.17	.22	.21
203	Rough rice............	5.18	.59	1.07	.32	.19
205	Rough rice............	5.31	.56	1.22	.31	.21
1	Rough rice[1]............	7.08	1.07	1.19	.21	....
[1]2	Rough rice............	4.39[2]	.51	1.33	.33	....
[1]3	Rough rice............	6.37[2]	.63	1.15	.35	....
	Average............	5.36	.61	1.20	.28	.20
	Maximum.........	6.37	1.07	1.33	.35	.21
	Minimum..........	4.01	.29	1.07	.21	.19
184	Rice straw............	16.57	.13	.63	1.86	.11
200	Rice straw............	13.97	.17	.89	1.66	.17
202	Rice straw............	12.71	.05	.55	1.40	.14
[1]1	Rice straw............	10.54[2]	.10	.48	1.28	....
[1]2	Rice straw............	15.80[2]	.23	.59	2.00	....
	Average............	14.90	.14	.63	1.64	.14
	Maximum	16.57	.23	.89	1.28	.11
	Minimum..........	10.54	.05	.48	2.00	.17

Amount of Rice Crop.—The rice crop may vary from three to thirty sacks (of 162 pounds) rough rice, per acre, according to conditions. In South Carolina and Georgia the average yield is given as eight to twelve sacks; in Louisiana, eight to eighteen sacks. The average yield for rice in 1903 is given by the United States Department of Agriculture as follows:

North Carolina	27.0 bushels.
South Carolina	17.7 bushels.
Georgia	30.5 bushels.
Florida	30.0 bushels.
Alabama	26.0 bushels.
Mississippi	35.5 bushels.
Texas	43.5 bushels.

Our figures will be based on a yield of 1900 pounds rough rice, which is the average for Texas in 1903, but above the average for other States in that year.

The proportion of rough rice to straw ranges between wide limits. According to the Louisiana Experiment Station (Bulletin No. 77, 1904), a comparison of many experiments by them shows fluctuations from 1582 to 2300 pounds of straw to 1000 pounds rough rice, the average being about two to one. The Brazoria Irrigation Company states that the average amount of straw is

[1] Bulletin 59, South Carolina Experiment Station.
[2] Pure Ash.

about two tons per acre. Some additional data is presented in Table III. For the basis of the calculations in this Bulletin, we will assume that an average crop of rice is 41 per cent rough rice and 59 per cent straw. A crop of 1900 pounds of rough rice produces 3000 pounds straw, which will accordingly serve as the basis for our calculations.

TABLE III.

Proportion of Straw to Rough Rice.

	Rough Rice, per cent.	Straw, per cent.	Roots, per cent.
South Carolina Experiment Station[1]	42.4	53.9	3.7
South Carolina Experiment Station[2]	51.2	48.8	....
Cow Bayou, Texas[3]	47.9	52.1	....
El Campo[4]	56.5	43.5	....
Japan[5]	41.4	58.6	....
Japan[6]	41.6	58.4	....

Total Amount of Food Consumed.—Based on 1900 pounds rough rice, the amount of plant food taken up by a crop of rice (exclusive of roots) would be as follows (Table IV):

TABLE IV.

Pounds of Plant Food per Acre Consumed by an Average Crop of Rice and Cotton, Oats and Corn.

	Phosphoric Acid.	Nitrogen.	Potash.
In 1900 pounds rough rice	11.6	22.8	5.3
In 3000 pounds straw	4.2	18.9	49.2
Total for rice	15.8	41.7	54.5
Cotton, 300 pounds lint	24	62	13
Oats, 30 bushels	37	27	9
Corn, 20 bushels	30	30	10

These figures present the amount of plant food estimated as taken up by the crop, and not the amount removed from the soil, which would be considerably less in the case of cotton; and rice, if the straw ashes are returned to the field. We see from the figures that an average crop of rice requires less phosphoric acid, but very much more potash than cotton, oats or corn. It also takes up more nitrogen than oats or corn, though less than cotton.

Plant Food Removed From Soil by Rice.—The amount of plant

[1] Entire plant with roots.
[2] As cut.
[3] Entire plant cut near ground.
[4] As cut. Length of straw 20 inches left in field, giving rough rice 39 per cent of grain and straw together.
[5] Average of six years experiments on 15 plots.
[6] Average of 26 plots.

food removed from the soil by a crop depends largely upon what disposition is made of it. With rice, first, the straw may be removed; second, burned and the ashes scattered; third, burned and the ashes not scattered; fourth, it may be used for fodder or bedding, and the manure placed on the land. The stubble may be burned or ploughed under. These different methods of disposing of the straw make a considerable difference in the amount of plant food removed, as is shown in Table V.

TABLE V.

Pounds per Acre of Plant Food Removed in a Rice Crop According to the Disposal of it.

	Phosphoric Acid.	Nitrogen.	Potash.	Commercial value.
In 1900 pounds rough rice..... .	11.6	22.8	5.3	$4.61
In 2250 pounds straw removed...	3.2	14.2	36.9	4.30
In 2250 pounds straw burned....	....	14.2	....	2.27
In burning 750 pounds stubble...	....	4.7	....	.75
Total loss in crop:				
1. If straw removed, stubble burned.	14.8	41.7	42.2	9.67
2. If straw burned and ashes scattered, stubble burned.	11.6	41.7	5.3	7.63
3. If straw removed, stubble ploughed under.	14.8	37.0	42.2	8.92
4. If straw burned and ashes scattered, stubble ploughed under.	11.6	37.0	5.3	6.88
5. If straw and stubble ploughed under.	11.6	22.8	5.3	4.61
Loss in other crops:				
Cotton, 300 pounds lint	9	22	9	....
Oats, 300 bushels.........	37	27	9	....
Corn, 20 bushels......................	30	30	10	....

The valuation of the plant food in column four of Table V is based on nitrogen at 16 cents a pound, phosphoric acid 6 cents, and potash 5 cents, which are the figures used for commercial fertilizers in Texas.

When rice straw is removed, it carries off plant food valued at $4.61 per acre. Burning the straw involves a loss of 14.2 pounds nitrogen, valued at $2.27, or an amount equal to that contained in about 200 pounds cottonseed meal. Burning the stubble loses 4.7 pounds nitrogen, worth 75 cents, and equal to about 70 pounds cottonseed meal. In other words, the application of 200 pounds per acre of cottonseed meal would just about replace the nitrogen lost by burning or removing the straw, and 70 pounds of cottonseed meal would be required to replace the loss in burning the stubble.

Removing rice straw from the field involves a loss of 37 pounds potash, valued at $1.85 per acre, and this loss could be replaced by the application of 75 pounds muriate or sulphate of potash. This loss of potash can be avoided if the straw is burned by simply scattering the ashes over the land they come from, instead of allowing them to stand in heaps and let the potash be washed out by rains. The nitrogen goes away with the smoke in burning, and is a total loss, but the potash remains in the ashes.

We have made a comparison between the plant food removed by rice, and by average crops of corn, cotton and oats, in which it is assumed that only the seed and lint of the cotton are removed, while the oat straw and corn stalks are taken off. (See Table V.) If the rice straw is removed, rice carries away over four times as much potash as cotton, corn or oats, but if the straw ashes are returned to the field, the loss is only one-half as much as with the crops named. Rice removes more nitrogen than cotton, corn or oats, and less phosphoric acid than corn or oats, but more than cotton. Besides the plant food removed by the crop, the soil loses phosphoric acid, potash and particularly nitrogen, in the water which seeps through the soil. This loss will be discussed (for rice) in connection with the composition of the irrigation waters.

II. RICE IRRIGATION WATERS.

The objects of the analyses of rice irrigation waters, were, first, to ascertain how much plant food they supplied to the plant or soil, and, second, to judge of their quality. The quality was good in all cases. The analyses are given on page 19.

The quantity of plant food supplied by the irrigation depends upon the quantity of the water used, and its composition. The gain or loss of plant food through irrigation is the amount brought on the soil by the water, less the quantity carried away in the seepage water, and the off-flow, when the dikes are cut.

Quantity of Water.—The quantity of water used in rice irrigation depends upon the rainfall and other conditions. Bond (Bulletin No. 113, Office of Experiment Stations, U. S. Department of Agriculture) gives the following data for two stations in 1901:

Depth of Water Used in Rice Irrigation.

	Raywood, Texas. Inches.	Crowley, La. Inches.
Irrigation water	19.66	16.47
Rainfall	9.15	10.04
Total	28.81	26.51
Period of irrigation	71 days.	79 days.

Other data in regard to this point are as follows:

	Inches Irrigation Water
Dr. Stubbs, Louisiana Station, Bulletin No. 77....	25*
Cow Bayou Canal & Irrigation Co., Orange, Texas..	24-25
E. S. Wood, El Campo, Texas....................	26†
Victoria Irrigation Co., Victoria, Texas..........	22†
Brazoria Irrigation Co., Brazoria county.........	16†

According to Professor T. U. Taylor (Bulletin No. 16 of the University of Texas), from the best evidence obtained in Western Louisiana and East Texas, it seems to be the consensus of opinion that 9 gallons water per minute are required for each acre of rice. In the Beaumont section the rainfall often reduces the pumping considerably. "During 1900, a wet year, some pumps were operated only four days, but a dry season will require the pumps to furnish all the 9 gallons per minute for each acre, and it is not good engineering to allow less than 9 gallons per minute." This would be a maximum amount required, and includes the loss from the canals before the water reaches the fields. One-half inch water per acre per day is 9.4 gallons per minute. The maximum amount of irrigation water to be pumped would be thus 42 inches, according to the length of the pumping season, sixty to seventy days, and the number of days the pumps are run. In Japan, according to *Inagaki,* on an average 6.4 gallons per minute per acre are required, while in Italy it is 16.8 gallons, according to *Patriarca.* The amount varies considerably according to climatic conditions. Considering all this data, but with most emphasis on exact measurements, we will make our calculations on the basis of 20 inches irrigation, or 4.5 millions pounds water per acre as the average amount applied. As an average between wet and dry seasons, this is perhaps a little high.

Plant Food in Water.—The amount of plant food in Texas irrigation waters is tabulated in Table VI. The analyses were made by colorimetric methods from samples collected in July-August, 1904. The Brazos river was unusually turbid (black rise) when the sample of water was collected, and as it probably contains more than the average amount of plant food, we will leave it out in discussing the results. We incline to believe that the phosphoric acid determinations are a little high.

Phosphoric acid varies from 0.1 to 3.4 parts per million, with an average of 1.7 parts; total nitrogen, from 0.22 to 0.45 parts per million; average, 0.31; and potash, 2.4 to 7.2 parts per million; average, 5.2.

In analyses made by the Louisiana Experiment Station (Bulletin No. 77, second series), from trace to 11.6 parts potash, and from heavy trace to 10.2 parts phosphoric acid per million were found in fifteen well and stream waters used in rice cultivation. Leaving out the exceptionally high prosphoric acid in one water,

*In addition to 20 inches rainfall.
†Calculated from data furnished.

the average is, for phosphoric acid, 0.9 parts per million; potash, 5.2 parts, and nitrogen, 1.0 parts. The average for nitrogen seems high in the Louisiana waters.

TABLE VI.
Plant Food in Irrigation Waters in Parts per Million.

Source.	Phosphoric Acid.	Nitrogen.					Potash.
		As Nitrites.	Nitric.	Free Ammonia.	Organic Ammonia.	Total.	
Guadalupe River.....	1.0	0.08	0.30	0.006	0.06	0.45	4.4
Cow Bayou............	0.1	0.02	0.08	0.04	0.09	0.23	2.4
Brazos River[1]..........	10.0	....	....	2.2	.62	2.82	8.0
Well, El Campo.	2.5	0.20	0.02	0.002	.001	0.22	3.2
Colorado River[2].......	1.6	0.10	0.05	0.10	0 15	0.40	7.2
Neches River..........	3.4	0.10	0.01	0.008	0.13	0.25	4.8
Average, except Brazos.	1.7	0.10	0.09	.03	.09	0.31	5.2

Table VII contains some other analyses of rice and other waters that are of interest. The determinations were probably made by gravimetric methods.

The sediment sometimes carried by these waters also contains plant food, and if deposited in appreciable amount must be of service in maintaining the fertility of the soil.

TABLE VII.
Phosphoric Acid and Potash in Waters, in Parts per Million.

Reference No.	Phosphoric Acid.	Potash.	Nitric Nitrogen.
1. Brazos River No. 1................	5.1	6.0	....
2. Brazos River No. 2................	9.6	20.6	....
3. Wichita River No. 1..............	2.1	18.3	....
4. Wichita River No. 2..............	Trace	6.3	....
5. Rio Grande..........................		26.5	....
6. Rio Grande..........................		18.9	....
7. Buffalo Bayou......................		4.8	0
8. Rio Grande..........................		6.7	0.2
9. San Antonio River		11.9	0
10. Prairie Bluff Rice Co		1.6	Trace
11. Pierce.................................		4.1	0.5
12. Eagle Lake..........................		0.3	0.4
13. Eagle Lake..........................		3.6	Trace
14. Louisiana waters average of 14.	0.9	5.2	0.17
Louisiana Maximum...............	10.2	11.6	....
Louisiana Minimum	0.2	0.8	....

1-6. Bulletin 104, Office of Experiment Stations, U. S. Department of Agriculture.
7-13. Analyses by Bureau of Chemistry, U. S. Department of Agriculture.
14. Bulletin Louisiana Experiment Station No. 77.

Plant Food Supplied by Water.—Based on 20 inches irrigation water, and the analyses just made, the amounts of plant food per

[1] Unusually turbid.
[2] Falling after a moderate rise.

acre are as follows (Table VIII). These figures do not include the plant food in the sediment sometimes carried, which, as stated, may be considerable at times. (See analysis of Brazos water, page 19.)

TABLE VIII.

Pounds per Acre of Plant Food Supplied by Irrigation Waters.

	Phosphoric Acid.	Nitrogen.	Potash.
Guadalupe River	4.5	2.0	19.8
Cow Bayou	.5	1.1	10.8
Brazos River	45.0	12.6	36.0
Well, El Campo	11.3	1.0	14.4
Colorado River	7.2	1.8	32.4
Neches River	15.3	1.2	21.8
Average, except Brazos	7.6	1.4	23.4
Required for rice crop	16	42	55
Lost from rice soil.			
When straw removed and stubble burned.	15	42	42
When straw burned and ashes spread on field, stubble turned under.	12	38	5

Table VIII shows that the average irrigation water supplies only a fraction of the nitrogen consumed by an average crop of rice, and not enough phosphoric acid or potash to grow an average crop. The sample of the Brazos river subjected to analysis indicates more than enough phosphoric acid for a crop, and nearly enough potash, but, as we have stated, this sample is believed to be unusually rich. However, the two analyses in Table VII indicate that the Brazos is often rich in plant food, sample No. 1 carrying phosphoric acid at the rate of 20.4 pounds per acre, and potash 28 pounds, and sample No. 2 carrying 43.4 pounds phosphoric acid and 92.4 pounds potash per 20 inches of water to the acre.

Table VIII indicates the total amount of plant food carried on the soil by the irrigation waters. The net gain or loss through irrigation is estimated when the amount of plant food lost in the off-flow and seepage waters is deducted.

Loss in Seepage and Off-flow Water.—The estimate of the loss of plant food in the seepage and off-flow water was made from the amount of plant food given up or lost from the soils in contact with water carrying various amounts of potash and phosphoric acid.

Method of Work.—Fifty grams soil were shaken with 250 c.c. water, or a solution of potassium phosphate (for phosphoric acid) or potassium sulphate (for potash). After setting half an hour, the solution was filtered through unglazed porcelain. Phosphoric acid was estimated colorimetrically after Woodman. Fifty c.c. were evaporated with 2 c.c. nitric acid, and heated two hours at the temperature of boiling water. It was then dissolved in water, treated with nitric acid and ammonium molybdate, and the color compared with the phosphoric acid solution before contact with the soil. As the soil extract was usually colored, a correction was made by comparing the solution with a standard before adding the ammonium molybdate, and this correction was subtracted from the reading.

Potash was determined by the colorimetric method of Cameron, the color of the solution before and after contact with the soil being compared.

Discussion of Results.—The results are exhibited in Table IX. Unfortunately the soils represent only a few districts, not all of the sections from which the waters came.

The irrigation waters would dissolve phosphoric acid from all the soils; the Brazos river, when unusually turbid, would give up some phosphoric acid to the soil, but under other conditions it would remove phosphoric acid.

With the exception of the black, sandy soil from Brazoria county, all the soils examined would apparently fix potash from the average water, and the Brazoria soil would take potash from the water under some conditions.

TABLE IX.

Phosphoric Acid and Potash Remaining in Solution After Contact of Soil With Solutions of Different Strength.

	Phosphoric Acid in parts per million.			Potash in parts per million.		
Original solution	10	4	0	8	2.5	0
After contact with:						
95 Black sandy soil Brazoria	5.1	2.7	3.1	3.2	2.8	3.1
96 Subsoil of 95	2.3	1.8	2.3	2.9	3.3	3.0
97 Heavy soil, Brazoria	2.3	1.6	1.4	2.4	1.4	1.4
98 Subsoil of 97	1.6	1.6	1.7	1.3	1.0	0.9
137 Beaumont soil	5.8	3.5	3.8	1.9	1.3	1.1
138 Subsoil of 137	5.0	1.6	4.2	1.1	1.0	0.6
141 Cow Bayou soil	....	2.8	....	3.5	2.5	2.3
142 Cow Bayou soil	8.0	4.0	5.3	2.1	1.9	1.8
Average	....	2.5	3.1	....	1.9	1.8

The gain or loss from the irrigation waters is estimated in Table X. The average is a gain of 3 pounds phosphoric acid, and 20 pounds potash. Individual cases may differ widely from this average, as does the Orange county soil, in which there is a loss of 4.9 pounds phosphoric acid and a gain of 7.6 pounds potash. However, a series of analyses of the waters ought to be made before any great emphasis can be laid on the figures for individual soils, as the waters vary in composition from time to time. The average figures are probably near the truth.

TABLE X.

Gain or Loss of Plant Food From Irrigation Waters, in Pounds per Acre.

	Phosphoric Acid.	Nitrogen.	Potash.
Average gain from 20 inches irrigation....	7.6	1.4	23.4
Average loss from 8 inches seepage and off-flow.	4.5	?	3.4
Average gain.............................	3.1	Loss	20.0
Estimated gain from Cow Bayou water....	0.5	1.1	10.8
Loss in seepage and off-flow, Orange soil...	5.4	?	3.2
Average gain (+) or loss (—).........	—4.9	Loss	+7.6
Estimated gain from Neches water..........	15.3	1.1	21.8
Estimated loss in seepage and off-flow, Jefferson soil.	2.9	?	2.3
Gain....................................	+12.4	Loss	+19.5

TOTAL LOSS OR GAIN BY RICE SOILS.

The average net loss of plant food from rice soils through the crop and irrigation water is presented in Table XI. When the straw is removed and the stubble burned, the loss from these sources is 12 pounds phosphoric acid, 42 pounds nitrogen, and 22 pounds potash. When the straw ashes are returned, the loss is 9 pounds phosphoric acid, 37 pounds nitrogen, and an apparent gain of 15 pounds potash. Some soils, such as those watered by the Brazos, and perhaps the Colorado, would lose less phosphoric acid or potash than the average. Others would lose more.

The loss of nitrogen is greater than for cotton, corn or oats. The loss of potash is twice as great as for cotton, corn or oats if the rice straw is removed. Otherwise, instead of a loss there is apparently an average gain. The loss of phosphoric acid is moderate.

In addition to these losses in the crop and off-flow and seepage waters, counterbalanced in part by the gain in the irrigation water, there is a loss by rain water percolating through the soil during the period it is not covered by crops. The loss of phosphoric acid and potash in this way is hardly large, but the loss of nitrogen may be considerable. Snyder (Bulletin No. 89 of the Minnesota Experiment Station) found a loss of nearly four pounds nitrogen by percolating water, etc., to every pound removed by the crop in continuous wheat farming. The proportion of loss is less as the amount of nitrogen in the soil decreases.

TABLE XI.

Net Gain or Loss of Plant Food From Rice Soils in Pounds per Acre.

	Phosphoric Acid.	Nitrogen.	Potash.
Average gain from irrigation water	3.1	Loss	20.0
I. Loss when straw removed and stubble burned, average.	15	42	42
Net loss due to crop and water..........	12+	42+	22+
Average gain from water..........................	3	Loss	20
II. Loss when straw ashes are returned, stubble ploughed under.	12	37	5
Net loss (—) or gain (+) due to crop and water.	—9	—37	+15
Removed by cotton..................................	9	22	9
Removed by oats......................................	37	27	10
Removed by corn.....................................	30	30	10

At the Rothamsted Experiment Station the average loss of nitrogen by percolation of water through a bare soil sixty inches deep, is 32.2 pounds per year for twenty-seven harvest years. If the soil were covered with vegetation, the loss would be less, as the vegetation removes the nitrogen from solution. Rice soils are mostly stiff and not easily penetrated by water; the loss of nitrogen by percolation during the winter might be placed at 20 pounds per acre, as an estimate which is perhaps a little high. The total loss of nitrogen per year from crop and water would then be 60 pounds.

Starting with a soil equally provided with phosphoric acid, nitrogen and potash, in forms that plants can take up, and placing it under continuous rice culture, we would expect a deficiency in nitrogen to appear first. A deficiency in potash would appear next, if the straw is removed, but if the straw ashes are returned to the field the phosphoric acid would be next in order to be deficient, and potash might last indefinitely. No soil, however, is equally rich in available phosphoric acid, nitrogen, and potash, and the order in which any deficiency would show itself under these conditions would depend on the amounts of available plant food present.

COMPOSITION OF THE IRRIGATION WATERS.

As we have already stated, the irrigation waters subjected to analysis were of good quality. The analyses are recorded in Table XII. It is hardly necessary to discuss these analyses in detail.

TABLE XII.

Composition of Rice Irrigation Waters in Parts per Million.

	Cow Bayou.	Guadalupe River.	Brazos River.	El Campo Well.	Neches River.	Colorado River.	Well, Algoa.
Carbonate of Lime	18	102	167	236	7	97	156
Sulphate of Lime	...	...	7	...	...	...	...
Phosphate of Lime	...	...	22	...	...	...	...
Carbonate of Magnesia	2	36	...	28	4	15	34
Sulphate of Magnesia	17	18	27	...	1	14	...
Chloride of Magnesia	...	...	80	...	44	...	26
Carbonate of Soda	...	...	...	30	...	...	...
Sulphate of Soda	26	20	...	...	...	...	...
Chloride of Soda	...	56	13	86	55	28	29
Chloride of Potash	3.8	6.9	13	...	...	...	...
Ferrous Carbonate	...	...	61	...	...	...	...
Silcia	[1]	[1]	96	[1]	[1]	[1]	[1]
Suspended matter	...	...	7865	...	85	374	...

III. CHEMICAL COMPOSITION OF RICE SOILS.

In the preceding pages we have discussed the amount of plant food required by rice, and supplied in the irrigation waters; we will now consider the composition of some rice soils, and their ability to supply the demand made upon them. The objects of the chemical analyses of soils are, to secure information in regard to the need of the soil for plant food, the wearing qualities of the soil, and the treatment under which its fertility will be maintained. Our knowledge is not sufficiently advanced to tell from a chemical analysis exactly what kind of plant food, and how much, will produce the best results on a given soil, for the reason that other factors than chemical composition are of decided influence, as will appear in subsequent pages. Chemical analysis does, however, furnish results that are of decided importance, for the questions above stated.

In making a complete chemical analysis, it is necessary to determine other constituents of the soil in addition to phosphoric acid, potash, and nitrogen, for the reason that these other constituents influence the fertility of the soil, as will appear later.

AVAILABLE AND UNAVAILABLE PLANT FOOD.

Most of the plant food in the soil can not be taken up by plants, since it is not in a suitable form. The plant food which can be taken up is termed *available.* Thus we speak of available phosphoric acid, available potash, available nitrogen. A soil that does not contain sufficient available

[1] Not determined.

phosphoric acid will require the application of a fertilizer carrying phosphoric acid even if it contains a large amount of total phosphoric acid. The fertility of a soil does not depend upon the total quantity of plant food it contains, but on the quantity of available food. By proper methods of treatment, the unavailable fertility of the soil is slowly converted into available fertility.

A sharp distinction between available and unavailable plant food can not be drawn, for the reason that availability is a relative term, and varies according to several groups of factors, namely, the nature of the plant, the weathering of the soil, the chemical composition of the soil, and physical conditions.

Nature of the Plant.—Plants have different powers for securing food, according to the time and season of their growth, root habit, and perhaps acidity of root juices.

Weathering of the Soil.—The compounds in the soil are undergoing a change by which unavailable food is converted into available. For want of a better term this may be termed weathering. Thus the amount of available plant food in the soil at planting will be increased by weathering agencies during the growth of the plant. On the other hand, some may be washed out and lost.

The rapidity of weathering depends upon the form in which the plant food exists in the soil, the presence of other substances, and the treatment to which the soil is subjected.

A soil may be farmed so that the weathering activities decrease rapidly from year to year. In such case the available plant food decreases, and the soil becomes poorer and poorer—"runs down." On the other hand, the run down soil may be treated so that the weathering activities increase, the fertility increases and the land is "brought up." In an ideal system of farming the weathering activities of the soil would be maintained at a profitable degree, supplementing any natural deficiency in phosphoric acid, potash, nitrogen or lime by use of the proper fertilizer and avoiding loss by washing or otherwise as much as possible.

Weathering is increased by increasing the amount of vegetable matter in the soil, if a suitable physical condition is maintained. Tillage also appears to increase weathering to a certain extent.

Chemical Compounds of the Soil.—Some compounds of potash, phosphoric acid and nitrogen in the soil are easily taken up by plants, that is, have a high degree of availability. From others, plants can get so little that the plant food in them may be termed unavailable. Between these two extremes are many degrees of availability, affected, as we have seen, by the nature of the plant, and by chemical changes brought about by weathering activities. The determination of the needs of a soil by chemical analysis is evidently no simple problem.

Physical Conditions.—Various physical conditions affect the availability of plant food. Chemical compounds which could be utilized by the soil may be enclosed in soil particles so as to be inaccessible to the roots of plants—hence unavailable. Two soils may contain the same percentage of available plant food, yet one offers a larger quantity than the other by virtue of being deeper. The permeability of the soil to air and water, the amount of water which it contains, and other physical conditions, most of which are profoundly influenced by ordinary farming operations, affect the weathering activities in the soil.

SOILS SUBJECTED TO ANALYSIS.

We did not receive as many rice soils as desired, so that several important rice growing sections are not represented. The conclusions drawn as to the quality of the soils we examined can not be applied to areas not represented. In addition soils from the same locality often vary decidedly in chemical composition and properties. The soils examined are numbered and described as follows:

No. 95. Brazoria county. Heavy black sandy soil; yield about ten sacks rice per acre. Samples taken to the depth of 12 inches. Probably the Lake Charles fine sandy loam of the Bureau of Soils.

No. 96. Subsoil of No. 95. Heavy sandy soil; depth 12-24 inches.

No. 97. Brazoria county. Heavy black land, very rich. Sample taken to the depth of 12 inches. Produces about fifteen sacks per acre. This is probably the soil mapped as Houston black clay by the Bureau of Soils.

No. 98. Subsoil of No. 97. Depth 12-24 inches.

No. 137. Jefferson county. Gray clay loam, near Beaumont. Produces about 14 sacks rice. Sample taken to a depth of 6 inches.

No. 138. Subsoil of No. 137. Taken to a depth of 6-12 inches.

No. 141. Orange county. Gray clay loam. Surface soil; under cultivation three years.

No. 142. Same as No. 141, from adjoining field; never cultivated.

No. 206. DeWitt county. Black calcareous clay from Cuero, Texas. Hog wallow land, second valley, above overflow. Yield, 6 barrels rice. Gummy in wet season, brittle in dry season. Taken to a depth of 9 inches.

No. 207. Black clay subsoil of No. 142, taken to a depth of 9-16½ inches.

No. 208. Unproductive clay from beneath summits of hog wallow, same field as Nos. 206 and 207. The hog wallows were leveled by scraping two years' age, yet every elevation can be traced by the difference in the color of the land, and the spots beneath the former summits of hog wallows are unproductive. Taken to a depth of 7 inches. This soil is practically a subsoil.

In addition are included some analyses of soils from the rice sections made by Dr. Loughbridge for the Tenth Census of the United States.

The Chemical Analysis.—In the chemical analysis of soils other constituents besides the plant food must be determined, for these affect the availability or rate of weathering of the plant food, or have other influence upon the soil. The analyses are given in Table XIII.

The analyses were made with the use of strong hydrochloric acid (1.115 sp. gr.) as a solvent. This does not dissolve all the phosphoric acid, potash, etc., from the soil, but dissolves that which is more active, and will become available to plants by weathering or otherwise. The figures give information chiefly in regard to the wearing quality of the soil. By comparing the soils with soils of known fertility, it is also possible to obtain indications as to the needs of the soils, which are often correct, but sometimes are not.

The soils from Jefferson, Orange, DeWitt, and Victoria counties and the black soils of Brazoria contain only small amounts of phosphoric acid, and will probably need fertilization with this substance in a short time. The soils of Harris county, the red Brazos bottom soil of Brazoria county, and the Rio Grande valley soil contain an abundance of phosphoric acid.

TABLE XIII.

Percentage Composition of Rice Soils.

	Brazoria County.		Brazoria County.		Jefferson County.		Orange County.		DeWitt County.			Harris County.*	Victoria County.*	Brazoria County.*	Rio Grande Valley, near Brownsville.*
	Heavy sandy.		Heavy black.		Prairie loam.		Prairie loam.		Heavy clay.			Sandy prairie.	Black waxy.	Red loam, Brazosbot.	
	Soil 95.	Soil 96.	Soil 97.	Subsoil 97.	Soil 137.	Subsoil 138.	Cultiv. 141.	Uncult.	Soil 206.	Subsoil 207.	Soil, hog wallow, 208.	Soil.	Soil.	Soil.	Soil.
Phosphoric Acid	.016	.036	.019	.014	.026	.023	.023	.02	.025	.045	.028	.156	.093	.148	.204
Nitrogen	.097	.078	.090	.068	.221	.092	.152	.129	.074	.088	.05	......	......	......	......
Potash	.08	.29	.137	.184	.143	.09	.06	.06	.396	.391	.282	.29	.43	.78	1.31
Lime	.24	.55	.53	.56	.24	.31	.09	.12	2.17	2.37	5.68	.65	1.05	1.88	14.43
Magnesia	.18	.50	.70	.72	.26	.22	.16	.10	.83	.76	.34	.27	1.09	1.91	1.53
Carbon Dioxide	.08	.027	.12	.02	.18	.005	.025	.03	.90	.91	2.92	......	......	1.96	9.91
Sulphur Trioxide	.04	.04	.05	.04	.07	.05	.05	.02	.014	.007	.04	.08	.28	.03	.04
Oxide of Iron and Aluminium.	3.45	6.39	12.10	11.94	5.46	5.08	2.91	1.92	7.26	7.94	7.79	8.48	12.53	7.72	13.20
Insoluble and Soluble Silica.	91.03	81.02	72.54	74.67	82.19	86.46	89.18	92.17	78.58	77.52	72.07	83.97	77.85	80.41	53.30
Loss on Ignition	4.04	5.81	9.20	6.69	8.37	5.87	5.38	4.20	5.74	5.27	6.66	5.31	5.91	4.04	6.01
Moisture	1.44	4.51	4.33	5.11	3.04	2.76	2.27	1.54	5.19	5.85	5.24	......	......	......	......

*Analyses by Loughbridge for the Tenth United States Census (1880).

The prairie loam of Orange county is deficient in potash; the other soils contain a sufficient amount. The soil of the Rio Grande valley is particularly rich in potash.

With the exception of the Orange county soil, all the soils contain enough lime. The ratio of lime to magnesia is unfavorable in soil No. 208 from the DeWitt county and the Rio Grande valley soil.

The cultivated and uncultivated soils from Orange county show no greater difference in composition than might be found in soils from adjoining fields, so no conclusions can be drawn here. Some difference will be observed in other chemical work, and will be discussed there.

The heavy clay unproductive soil from DeWitt No. 208 differs from the productive soil in containing much less nitrogen and humus, and the ratio of lime to magnesia is unfavorable. The soil is probably deficient in nitrogen. It is really a subsoil. A liberal application of stable manure has been recommended for the unproductive spots and also the trial of commercial fertilizers.

Method of Analysis.—The analyses were made by the methods of the Association of Official Agricultural Chemists, with the exception of potash, which was determined as follows:

One hundred c.c. solution (=2 gm. soil) was evaporated in a platinum dish with ammonia and ammonium carbonate, and ignited gently. The residue was dissolved in hot water, filtered and washed into a porcelain dish with water, the solution acidified with hydrochloric acid, and potash determined in the filtrate by the usual method. This method takes less time and is more easily manipulated than the official method.

Determination of Sulphates.—On account of the small quantity present, the determination of sulphates by the official method was supplemented by analyses with the nitric acid method. That is, a sample of the soil was evaporated with nitric acid, nitrate of potash added, and the residue ignited. The determination was then completed by the usual method.

Percentage of Sulphur by two Methods.

Soil.	95	96	97	98	137	138	141	142
Official	.04	.04	.05	.04	.07	.05	.05	.05
Nitric Acid	.07	.05	.05	.04	.10	.19	.08	.07

The results were always higher by the nitric acid method, sometimes decidedly so. Some of the sulphur is undoubtedly present in organic forms of combination, and sometimes as sulphides.

Amount of Plant Food Present.—The amount of plant food dissolved from the soil by strong hydrochloric acid (in pounds per acre-foot) is shown in Table XIV.

From the amount of plant food removed by an average crop of rice and supplied in the average irrigation water, it can be calculated that the amount of plant food present is sufficient for the following numbers of crops according to the soil:

	Straw removed.	Straw burned and ashes returned.
Phosphoric acid, from	40 to 75 crops	55 to 100
Nitrogen, from	40 to 120 crops	40 to 120
Potash, from	90 to 600 crops	No apparent loss.

TABLE XIV.

Pounds of Phosphoric Acid, Nitrogen and Potash in Rice Soils per Acre to the Depth of a Foot.

Ref. No.	Soil.	Phosphoric Acid.	Nitrogen.	Potash.
95	Brazoria county, black sandy soil	500	3200	2600
97	Brazoria county, heavy land	600	3000	4500
137	Jefferson county, prairie loam	800	5210	3800
141	Orange county, prairie loam	800	5060	2000
142	Orange county, uncultivated	700	4300	2000
206	DeWitt county, heavy clay	800	2470	13200
208	DeWitt county, heavy clay	900	1700	9800

These figures do not cover the loss from percolation during the winter, probably small for phosphoric acid and potash, large for nitrogen. Assuming the loss of nitrogen in this way and in the crop and irrigation waters to be 60 pounds per acre, this store of nitrogen would last twenty-eight to seventy-two years.

According to these figures, the nitrogen would be exhausted first, the phosphoric acid next, and the potash last of all if the straw ashes are returned to the soil. It is not the total plant food which produces the crop, but the available. The available plant food decreases much more rapidly than the total.

Detailed Discussion of Results.—The analyses with strong hydrochloric acid give information chiefly in regard to the wearing qualities of the soil, indicating which element will probably become deficient first. By comparing analyses made in this way with analyses of soils of known fertility it is also possible to obtain indications as to the needs of the soil. As a rule, soils of high fertility and which wear well under cultivation contain relatively large quantities of plant food. Often an exception to the rule is found, in which a good soil contains only moderate amounts of plant food, but in this case the plant food is present in more favorable combinations than usual.

By an examination of the analyses we can then obtain some indications as to the needs of the soil. We will consider first the lime, then the lime and magnesia ratio, then the potash, phosphoric acid, nitrogen, acidity and organic matter.

Lime.—The lime in soils is present as silicates, carbonates, sulphates, and phosphates. The lime in silicates is slowly changed by weathering to carbonates.

The carbonates and sulphates of lime are active forms of lime. The easily decomposed silicates may also be considered as active.

Active lime compounds in the soil aid in rendering the nitrogen of the soil available, prevent the soil from becoming acid, improve its physical condition and appear to be associated with a higher degree of availability of the total phosphoric acid.

Hilgard (Report of the California Experiment Station, 1888-1889), after considering the analyses of a large number of soils in the South and West, presented the following standards for total lime. They have not found general acceptance, but give a good working basis:

	Lime.
In light sandy soils, not less than..............	0.10
In clay loams, not less than....................	0.25
In heavy clay soils, not less than..............	0.50

Judged by these standards, all the soils contain enough lime except the Orange county soil. The DeWitt soils contain an abundance of lime.

Again, considering the carbonic and sulphuric acids to be combined with the lime, the surface soils of all excepting Cow Bayou contain enough active lime.

Ratio of Lime and Magnesia.—According to Loew, the ratio of lime to magnesia in the soil influences crop production. Aso studied the effect of this ratio on rice, with pot experiments with the following results (Bulletin College of Agriculture, Toyko Imperial University *6* [1904] 97).

TABLE XV.

Effect of Lime-Magnesia Ratio on Rice Crop.

Ratio $\frac{CaO}{MgO}$	Rough Rice. (gm)	Straw. (gm)
5/1	20.5	53.5
4/1	30.5	59.5
3/1	44.0	65.5
2/1	58.5	96.0
1/1	98.5	125.0
1/2	84.0	95.5
1/3	79.0	106.

According to this experiment, the most favorable lime-magnesia ratio for rice is 1:1. An increase of lime is more injurious than an increase of magnesia.

Applying these considerations to the rice soils we have analyzed, it is seen that the lime-magnesia ratio is favorable in all except the soil from DeWitt and the Rio Grande valley. In soil No. 206, CaO:MgO::2.6:1, and in soil No. 208 the ratio is 17:1. In view of the fact that while the DeWitt soils apparently contain an abundance of plant food, soil No. 206 yields only six barrels rice per acre, and soil No. 208 is unproductive, it is possible that fertilization with magnesium salts would prove remunerative. On the other hand, we must remember that soil No. 208 is practically a subsoil, and subsoils are usually unproductive until mellowed by weathering.

Potash.—Hilgard's standards for potash are as follows:

In sandy soils of great depth may be less than....	0.1 %
In sandy loams	0.1 to 0.3 %
In loams	0.35 to 0.45%
In heavy clays and clay loams..................	0.45 to 0.80%

Judged by these standards all the soils are low in potash, but probably contain a sufficient amount, except the Orange county soil, which is particularly low. The soils contain from 2000 to 13,200 pounds of potash per acre to the depth of a foot, enough for a good many crops of rice. The problem is to maintain a supply of it in such forms that the rice can take it up. We have seen that if the rice straw ashes are returned to the soil there is apparently a gain of potash by the soil under rice culture. It is hardly possible that such gain really takes place.

Phosphoric Acid.—Hilgard's standards for phosphoric acid are as follows:

Seriously deficient in sandy soils unless accompanied by a large amount of lime..............................	0.05%
Sandy loams with a fair supply of lime.................	0.1 %
Sandy loams with poor supply of lime...................	0.2 %
Clayey soils not less than............................	0.2 %

Excepting the Harris county soil, the Brazoria red loam and the Rio Grande valley soil, all the rice soils are very low in phosphoric acid. Comparison with fertile soils leads to the same conclusion. In Minnesota, in only three out of seventy-two soils was there less than 0.10 per cent phosphoric acid, and the average was 0.20 per cent (Minnesota Experiment Station, Bulletin No. 65).

Michigan wheat soils contain about 0.33 per cent phosphoric acid. Veitch found in type samples of Maryland soils from 0.024 to .155 per cent phosphoric acid, and goes on to say: "Judged by Hilgard's standards all these soils are low in phosphoric acid—when compared with the strong western soils they are markedly low. The deficiency is accentuated in the majority of cases by a low lime content. These conclusions are in harmony with farm experience all over the State, namely, larger returns are realized from an application of phosphoric acid than from application of nitrates or potash salts."

We must conclude that the rice soils examined are low in phosphoric acid, and will probably be found deficient in this respect, if not immediately, yet in a short time.

Nitrogen.—Soils of average fertility usually contain 0.15 to 0.20 per cent nitrogen. Prairie soils of average fertility may contain higher percentages.

While the nitrogen content of the soils is not high, they can not be said to be deficient in nitrogen, except in case of the DeWitt soil No. 208, which is evidently deficient in this element.

The nitrogen supplied to plants by the soil does not depend upon the total quantity present, but on the changes in the soil which render it available. The rapidity of these changes depend on the composition of the soil, its treatment, etc., and is slower in rice soils than in soils not covered with water. In view of the fact that rice draws heavily upon the nitrogen content of the soil, that other losses occur, and that the nitrogen content of the soils is not high, these soils will probably require nitrogen before long.

Humus.—The term humus is applied here to that portion of the organic matter of the soil which is soluble in ammonia after the lime is removed. Humus is important on account of its effect upon the physical properties of the soil; some also believe it holds in combination some of the available plant food in the soil. All organic matter, including humus, in its decay acts upon the unavailable plant food of the soil, gradually rendering it available. The fertile soils of the world generally are rich in organic matter. Minnesota soils contain on an average 3.66 per cent humus.

Humus was determined by three methods: (a) the official method, (b) precipitating suspended soil particles with 5 gm. potassium chloride per liter (after Schloesing), and (c) filtration through a porcelain tube to remove soil particles (Cameron). The results are presented in Table XVI.

The official method gives the highest results: filtration through a porcelain tube the lowest. The solution by the official method contained in each case more or less suspended soil particles which were precipitated by addition of potassium chloride.

The official method evidently gives too high results on account of the presence of hydrated soil particles. The precipitation method may give results a little low, since the bulky precipitate formed in many cases may carry organic matter down with it. The filtration method gives low results, as the filter acts somewhat as a semi-permeable membrane and diffusion interferes with the filtration to a greater or less extent, as pointed out by Briggs. We have further tested this point on a solution of gelatine, with the following results:

	In 25 cc.
Original solution	.0905 gm.
First 25 c.c. filtered	.0082 gm.
Third 25 c.c. filtered	.0023 gm.

Gelatine was deposited on the outside of the porcelain tube.

TABLE XVI.

Percentage of Humus by Different Methods.

Soil.	Method.		
	Official.	Precipitated with KCl.	Filtered through tube.
95 Brazoria	2.22	1.24	1.02
96 Subsoil of 95	3.92	1.08	0.90
97 Brazoria	5.27	....	1.12
98 Subsoil of 97	4.88	2.58	1.00
137 Jefferson	3.04	2.20	1.30
138 Subsoil of 137	3.12	1.48	1.05
141 Orange	2.70	1.54	1.28
142 Orange	1.73	1.48	1.35
206 DeWitt	....	1.96	....
207 Subsoil of 206	....	2.07	....
208 DeWitt, unproductive	....	....	....

Acidity.—Dr. Wheeler, of the Rhode Island Experiment Station, has shown that an acid condition of the soil is injurious to many. plants, particularly sorghum, onions, and cantaloupes. Rye is least injured by acidity. This, in turn, is followed by oats, wheat, and barley, in regular order. Corn does better on non-acid than on an acid soil.

The acidity of three rice soils was determined by the method of Hopkins et al. The results are expressed in terms of carbonate of lime, as follows:

No. 97, Brazoria soil, acidity........... 97 parts per million.
No. 141, Orange soil, acidity............342 parts per million.
No. 137, Jefferson soil, acidity............113 parts per million.

To neutralize the acidity on the surface foot of these soils would require the following amounts of quick lime or of ground limestone per acre:

	Quicklime.	Ground Limestone.
Brazoria county	180	323
Orange county	640	1140
Jefferson county	210	380

The Brazos river carries enough carbonate of lime to neutralize the acidity of the Brazoria soils every year. The Cow Bayou water would require over sixteen years to neutralize the acidity of the Orange soil, and the Neches river would take nearly eight years. The Brazoria soil would hardly require liming to remove its acidity, while the other soils might.

Referring to the table XIII, on page 23, the Brazoria soil No. 97 is seen to contain 0.12 per cent carbon dioxide, the Jefferson county soil 0.18 per cent, and the Orange county soil 0.025 per cent. Considering also the fact that the Brazos water carries enough lime to neutralize the acidity of the soil every year, we must remark that it is doubtful if the Brazoria or Jefferson soils are really acid at all, and if this is so, the method used for determining acidity must give incorrect results.

Liming is recognized as of benefit for rice soils in Japan. According to Aso: "The farmers of Japan generally apply too much lime, and the injuries thus produced have induced the local government of Kiushiu to issue a law prohibiting the use of lime. Besides the depression of the harvest a greater brittleness of straw and grain and a relative decrease of protein result from excessive liming."

Rice appears to endure greater acidity of soil than other plants, and liming to remove acidity may sometimes not be of advantage. It has also been found in Japan that liming may decrease the availability of fertilizer phosphoric acid for rice.

It is thus possible that moderate liming would be of benefit on these acid soils poor in phosphoric acid. We would suggest the trial of lime on small areas, and in moderate amounts in Orange and Jefferson counties.

TEST FOR DEFICIENCIES BY POT EXPERIMENTS.

Pot experiments to test for soil deficiencies were made on three of the soils.

Fifteen pounds soil were placed in galvanized iron pots. The pots received the following addition:

Pot PN. 2.5 gm. acid phosphate, 2.5 gm. nitrate of soda.
Pot PNK. 2.5 gm. acid phosphate, 2.5 gm. nitrate of soda, 1 gm. sulphate of potash.
Pot NK. 2.5 gm. nitrate of soda, 1 gm. sulphate of potash.

Eight seeds of cotton were planted in each pot, and thinned to four plants. On account of the limited quantity of soil on hand the pots were not planted in duplicate. No attempt was made to bring the plants to maturity.

The results are as follows (Table XVIII):

TABLE XVIII.

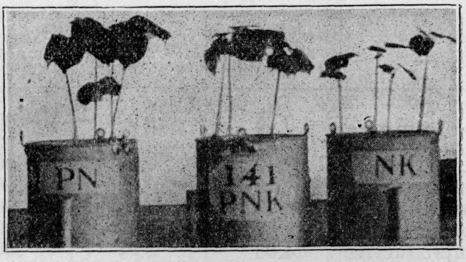
Pot Experiments with Rice Soil.

Soil.	Date of Planting.	Date of Harvest.	Grams Dry Matter per Pot.		
			PN.	PNK.	KN.
97	July 20.	Sept. 8.	7.4	6.9	3.1
137	July 25.	Sept. 8.	5.2	4.9	2.5
141	July 15.	Sept. 8.	5.5	3.6	2.4

From the results of this experiment we conclude that three soils need available phosphoric acid for cotton, and have no need of potash for this plant. (See photographs, page 31.)

97. Brazoria County Soil.

137. Jefferson County Soil.



141. Orange County Soil.

The plants with phosphoric acid, nitrogen and potash (PNK) are larger than those with nitrogen and potash (NK).

TEST FOR DEFICIENCIES WITH WEAK SOLVENTS.

Dilute solutions of nitric acid, citric acid, hydrochloric acid and other substances have been proposed to determine the chemically available phosphoric acid and potash in the soil. As we have previously pointed out, the plant food that can be taken up by the plant depends upon other conditions besides the chemically available food. This determination gives results of value, however.

For the purposes of this work, N/5 nitric acid was used, following the method of the Association of Official Agricultural Chemists, with the following modification. The method calls for a preliminary digestion to ascertain the amount of N/5 acid neutralized by the bases of the soil, with correction for this amount. The bases so neutralized are supposed to be carbonates, but this supposition is not justified. We compared the carbon dioxide determined direct with the amount calculated from the acid neutralized, and found the latter to be considerably larger. (See Table XIX.)

Some of the lime and magnesia neutralized must come from the calcium and magnesium in silicates decomposed by the solvent, and correcting the acid neutralized by them, must increase the solvent action on these substances. In this correction the oxides of iron and aluminium dissolved are not considered, as their salts are acid towards phenolphthalein.

In this work correction has been made only for the carbonates as determined by gravimetric methods. We are doubtful whether it would not be better after all not to make any correction for neutralization, as recommended for Dyer with citric acid.

The results are presented in Table XIX.

The amount of chemically available potash and phosphoric acid in pounds per acre-foot is presented in Table XX.

TABLE XIX.

Plant Food Soluble in Weak Solvents.

Soil	Carbon dioxide (per cent)		Percentage of	
	Calculated for acid neutralization.	Gravimetric.	Phosphoric Acid.	Potash.
95 Brazoria	0.28	0.076	.0020	.0066
97 Brazoria	.61	.12	.0007	.0074
137 Jefferson	.40	.18	.0029	.0128
141 Orange, cultivated	.18	.025	.0018	.0060
142 Orange, uncultivated	.13	.030	.0023	.0091
206 DeWitt	1.69	.90	.0051	.0298
208 DeWitt, unproductive	4.03	2.92	.0065	.0206

TABLE XX.

Phosphoric Acid and Potash Chemically Available in Pounds per Acre.

	Phosphoric Acid.	Potash.
95 Brazoria county sand	67	220
97 Brazoria county heavy land	23	247
137 Jefferson county	97	427
141 Orange county cultivated	60	200
142 Orange county uncultivated	69	303
206 DeWitt county	170	993
208 DeWitt county unproductive	216	786

Interpretation of Results.—According to Veitch, Maryland soils which need potash fertilizers contain less than 300 pounds potash per acre soluble in N/5 hydrochloric acid. The Brazoria and Orange county soils would be deficient in potash if this was the case, but the large crops produced by one of the Brazoria soils (No. 97) indicates that no deficiency exists at present. Perhaps rice has a greater power of getting potash than the crops grown on the Maryland soils, and perhaps the soils will need potash in a few years.

Maryland soils, all of which receive benefit from phosphoric acid, contain, most of them, 15 to 85 pounds per acre phosphoric acid soluble in weak acids, though three contain from 203 to 1300 pounds. The heavy soil in Brazoria county, which probably gives the best crops, contains the least phosphoric acid soluble in weak acids. Our pot tests show it to be deficient in phosphoric acid for cotton, however.

The conclusion that these soils, Brazoria, Jefferson, and Orange, will probably need phosphoric acid in a few years also appears justified. Phosphoric acid fertilizers are now being used with advantage in Louisiana.

TEST FOR DEFICIENCIES FOR NITRIFICATION.

The change of unavailable to available nitrogen in the soil is brought about by living organisms, the most important compounds produced being nitrates and ammonia. On account of the unfavorable conditions of rice culture for nitrification (and favorable for denitrification)—a compact soil, shallow ploughing, the soil saturated with water during a large part of the period of crop growth—little production of nitrates will take place, and the plant must take up a part of its nitrogen in other forms.

It has been shown by the writer that some soils are deficient in available phosphoric acid, potash or basic lime for the nitrifying organisms, and there may be a connection between deficiency for nitrification and deficiency for some crops. Without going into details, the following are the results of nitrification tests on some rice soils (Table XVII):

TABLE XVII.

Deficiences for Nitrification in Rice Soils.

Addition to Soil.	Percentage of added Nitrogen converted into:			Relative Effect based on	
	Nitrates.	Ammonia.	Total.	Nitrates.	Total Change.
Soil No. 97—Brazoria:					
Nothing	10.9	45.1	56.0	100	100
Carbonate of Lime	31.3	32.7	64.0	287	114
Potassium Sulphate	7.6	53.0	60.6	70	108
Acid Phosphate	8.0	48.1	56.1	73	100
Carbonate of Lime and Acid Phosphate.	36.0	29.9	65.9	330	117
Soil No. 141—Orange Co.:					
Nothing	7.5	56.4	63.9	100	100
Carbonate of Lime	31.8	37.3	69.1	424	108
Potassium Sulphate	6.5	55.9	62.4	87	98
Acid Phosphate	5.4	54.8	60.2	72	94
Carbonate of Lime and Acid Phosphate.	39.9	30.3	70.2	532	110
Soil No. 137—Jefferson County.					
Nothing	15.6			100	
Carbonate of Lime	26.4			169	
Sulphate of Potash	17.2			110	
Acid Phosphate	11.5			73	
Carbonate of Lime and Acid Phosphate.	24.9			159	
Soil No. 208—DeWitt.					
Nothing	42.1			100	
Acid Phosphate	42.3			100	
Sulphate of Potash	41.6			99	

Discussion of Results.—Carbonate of lime had a great effect upon nitrification in all save the DeWitt soil, which latter is rich in this substance, and some effect on the total amount of nitrogen made available in the soils in which it was determined, the first two. Sulphate of potash increased nitrification slightly in one case, decreased it or had no effect in the others. Acid phosphate alone exerted a depressing effect, but with carbonate of lime increased nitrification in the first two soils.

We must conclude that two of the soils are deficient in phosphoric acid and all except one in basic lime, for nitrification. In view of the fact that the nitrifying organisms have greater need for basic lime than plants, since the product of their life action is acid (nitric acid), it does not follow that the soils need basic lime for higher plants. On the other hand, phosphoric acid is probably needed.

Production of Available Nitrogen in Rice Soils.—The available nitrogen in the soil, that is, the nitrogen in forms which can be taken up directly by plants, is usually moderate at any given time, and the plant is dependent to some extent upon processes which change unavailable into available nitrogen. While plants can utilize certain organic nitrogenous bodies, it is probable that most cultivated plants get their nitrogen from two sources—ammonia and nitrates. Ammoniacal and nitric nitrogen can then be considered as the chemically available nitrogen of the soil.

The amount of nitric and ammoniacal nitrogen in the rice soils received was as follows:

Chemically Available Nitrogen in Pounds per Acre.

	Brazoria soil 95.	Brazoria soil 97.	Orange soil 141.	Jefferson soil 137.
Nitric Nitrogen	22.0	12.0	54.0	10.0
Ammonia Nitrogen	13.0	50.7	26.3	31.0
Total	35.0	62.7	80.3	41.0
Consumed by rice crop exclusive of roots.	41.7			

Some of the nitrates were probably produced while the samples were drying out. As the plant can not exhaust the soil of all its available nitrogen, there is not enough present to satisfy the needs of one crop, in at least two of the soils. The supply of chemically available nitrogen is produced, as we have seen, by the action of minute organisms acting on the soil.

While the soil is dry in winter and spring, some nitrification takes place, and the rice plant finds some nitrates for its first stages of growth. But during the season of flooding, nitrification can hardly take place; reduction of nitrates, or denitrification, would be more probable, so that the plant must feed mostly on ammonia. The production of ammonia in rice soils is less than in a cultivated soil. The amount of ammonia and nitrate nitrogen produced in two soils (not rice soils) with varying amounts of water, is presented in Table XXI. The details of this work will be published elsewhere. The soils were provided with cottonseed meal and kept four weeks at 35 degrees.

TABLE XXI.

Nitrates and Ammonia Nitrogen in Parts per Million.

Water present in per cent of saturation capacity.	Production of Nitrogen as Nitrates.	Ammonia	Total.
Soil 77:			
22.2	87.0	238.8	325.8
33.3	123.0	199.8	322.8
55.5	92.4	249.6	342.0
77.7	—2.8	229.8	227.4
100	—4.8	118.2	113.4
Soil 76:			
22.2	30.0	185.4	215.4
33.3	22.2	185.4	207.6
55.5	42.0	195.6	237.6
77.7	3.6	148.2	151.8
100	4 2	126.0	130.2

In the saturated soils denitrification occurred in the first one, and only a very small amount of nitrification in the second. The total amount of chemically available nitrogen produced was also considerably less than in the unsaturated soils.

IV. TREATMENT OF RICE SOILS.

In making recommendations for the treatment of rice soils, the following facts brought out in the preceding pages are considered:

1. A heavy loss of potash takes place if rice straw is removed.
2. The loss of nitrogen from rice soils is heavy.
3. The many of the soils examined are deficient in phosphoric acid.
4. The soils from Orange and Jefferson counties are acid.

Disposal of Rice Straw and Stubble.—The best way to dispose of the rice straw would be to use it for feeding and litter, and place the manure on the land. This is practicable only to a limited extent.

Burning the straw is wasteful, but if it is burned, the ashes should be scattered on the field from whence they come. If possible, the straw should be sold for enough to pay for the plant food contained in it, the expense of handling, and leave a profit on the transaction. Burning the straw and stubble involves a loss of nitrogen worth $2.97 per acre, at present prices.

The stubble should be ploughed under, if possible, instead of burning. In addition to avoiding a loss of nitrogen (75 cents per acre), the stubble adds organic matter to the soil.

MAINTENANCE OF NITROGEN SUPPLY.

As the soils do not contain large quantities of nitrogen, and the loss is heavy, nitrogen must be added before many years.

There are only two practical ways of adding nitrogen—by using fertilizers and by growing leguminous crops.

Using fertilizers to supply nitrogen for rice soils is at most a temporary expedient, and is adapted only to supplement the available nitrogen of the soil, though it will no doubt prove profitable for a time. As the available nitrogen naturally produced in the soil each year decreases, the profit for the application of fertilizer nitrogen for rice growing will also decrease, until it disappears. To restore the entire annual loss of nitrogen (60 pounds) by fertilizer nitrogen at 16 cents a pound would cost $9.60 per acre, which would hardly be profitable at the present prices of rice. Eventually some other method of securing nitrogen, partly or completely, than through fertilizers must be adopted.

Leguminous crops take nitrogen from the air, often in considerable amounts. For example, Penny, of the Delaware Experiment Station, found 131 to 188 pounds nitrogen per acre in a crop of red clover, part of which doubtless came from the soil, but a good part from the air. This would be enough nitrogen for at least two crops of rice. Cowpeas, soja beans, alfalfa, peanuts, velvet bean, clover, vetch, bur-clover, etc., are leguminous crops.

To maintain the supply of nitrogen in rice soils, we would, therefore, recommend the growing of leguminous crops at suitable intervals. They could be ploughed under, pastured off (if the soil permits), or cut for hay. In the latter case, half or less of the nitrogen would remain in the litter and roots, and the crop must be grown oftener to maintain the nitrogen supply. Care must be taken if the crop is ploughed under, as the addition of a large mass of decaying vegetation may sour the soil and injure it.

The best leguminous crops to grow, and the method of growing, time, etc., is a matter of practical farming that must be worked out by the rice growers, or by means of experimental tests. As conditions vary, quite different systems may be adopted in the various portions of the rice belt. The leguminous crops could be grown as a fall and winter crop, or as a season crop, or both.

If grown as a fall and winter crop, only a limited number of winter growing plants are available, such as vetch and clover. The crop is planted about the time of harvest, and allowed to grow until the following spring. It is then ploughed under. This method has the advantage, that the growing crop largely prevents the loss of plant food by percolation during the winter.

In growing leguminous crops as season crops, the land is given up to them instead of being planted in rice. The crop is ploughed under, pastured, or cut for hay, according to conditions. This method of soil treatment, properly carried out, should have the effect of killing water weeds and red rice.

Maintenance of Phosphoric Acid.—The phosphoric acid supply can be maintained only by addition of phosphoric acid in the form of fertilizers when it begins to be needed. Under some conditions, and for small farms, the phosphoric acid can be purchased in feeding stuffs, and applied in the manure, but this method is not practicable under the conditions of rice farming. Some of the rice soils already appear to be deficient in phosphoric acid, and it is probable that its application will prove profitable before long. It is already in use in Louisiana. One hundred pounds acid phosphate gives an increase of two or three sacks rice per acre. We would suggest the trial of 100 pounds acid phosphate per acre, particularly on the Orange, Jefferson, Brazoria, and Victoria soils.

Phosphoric acid may be obtained in other forms than acid phosphate. The relative values of the phosphoric acid in the different materials depend upon the nature of the soil to a large extent.

Experiments with different materials in Japan have given the following results (Table XXII):

TABLE XXII.

Relative Values of Phosphoric Fertilizers for Rice.

Kind of phosphate.	Relative increase when increase by 1 lb. phosphoric acid in acid phosphate=100.		Comperative m o n e y value, cents per pound.	
	First season.	Including first season and after effect of 4 years.	First season.	Five seasons.
Acid phosphate.........	100	100	7*	7
Precipitat'd phosph'te	107.1	110.5	7.5	8.2
Peruvian guano........	33.5	63.9	2.3	4.5
Thomas phosphate.....	49.5	84.0	3.5	5.9
Steamed bone dust.....	53.5	78.3	3.7	5.5
Crude bone dust.......	60.2	77.2	4.2	5.4
Bone ash	29.1	36.0	2.0	2.5
Phosphorite	13.0	30.9	0.9	2.2

Both the relative values and the money values based on increase of crops are given, the latter based on 7 cents a pound for the phosphoric acid in acid phosphate. According to these figures, if a ton of acid phosphate containing 14 per cent phosphoric acid (=280 pounds per ton) is worth $19.60 per ton, a ton of bone dust containing 23 per cent phosphoric acid would have an agricultural value of $25.30, on the basis of the increase in five seasons. The availability of bone depends upon the fineness with which it is ground; the coarser it is, the less rapidly plants can take it up. Ground phosphate rock containing 35 per cent phosphoric acid would be worth $15.40 per ton, if we take the increase of crop produced in five seasons for a basis. Taking the increase in one season only, it would be worth $6.30 per ton.

For the first season 100 pounds 14 per cent acid phosphate=101 pounds crude bone dust (23 per cent)=310 pounds 35 per cent phosphate rock. For five seasons, 100 pounds acid phosphate =79 pounds crude bone dust=129 pounds phosphate rock.

These figures are based on the Japanese experiments quoted, the soil of which was rich in vegetable matter. We would state again that the relative values of these materials depend upon the nature of the soil. In soils containing much vegetable matter the insoluble phosphates (bone meal, rock phosphate, etc.), are more available than in soils containing small amount of vegetable matter. We are inclined to believe, however, that the use of ground phosphate rock or bone dust, if purchased at a fair price, would prove profitable on rice soils.

Maintenance of Potash.—The supply of available potash in the soil should be maintained, so far as possible, by keeping up the activities of weathering. If this can be done, the soils will provide enough potash for a long time to come. The growing of

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*The valuation of available Phosphoric Acid in Texas this season is six cents a pound.

leguminous crops, with feeding them off or ploughing them under, will aid in maintaining the potash supply, for the vegetable matter so placed in the soil, in its decay, acts upon the unavailable potash, converting it into available forms.

Excepting the Orange county soil, which may perhaps be deficient, the other rice soils examined apparently contain enough potash. When the supply of available potash runs low, if it can not be increased by proper cultural methods, recourse must be had to fertilizers carrying potash, such as sulphate of potash, muriate of potash, or kainit, alone or in mixed fertilizers.

Most of the potash taken up by the rice plant is in the straw. The disposition of this will have a great effect upon the potash content of the soil, as already pointed out.

The Vegetable Matter.—The decaying vegetable matter in the soil is important, as it aids in changing the unavailable phosphoric acid and potash to available forms. In order to take as full advantage as possible of the plant food stored in the soil, it is thus necessary to maintain the amount of vegetable matter at a proper quantity. Ploughing under the stubble aids in this respect, but probably would not be sufficient. Treatment with leguminous crops, as recommended for maintaining the nitrogen, would be sufficient.

Liming.—Liming rice soils would hardly be of advantage west of Houston; on the gray prairie soils east of Houston it might be of advantage. For the reasons already given, the use of lime should be tested on a small scale at first, and only in moderate amount.

If ground limestone or marl is used, it should be spread broadcast and harrowed in. Quicklime should be slaked in some convenient place, spread broadcast and harrowed in.

Use of Magnesia.—Magnesium salts might prove advantageous on the Brownsville and DeWitt soils. Kainit, as it carries magnesia, may be a good source of potash for these soils, but under proper treatment neither may need potash in some time.

Magnesia can be applied as magnesium sulphate, 100 pounds per acre, or magnesite, 300 or 400 pounds per acre.

SUMMARY.

This bulletin is a study of the chemical composition and properties of some rice soils, rice irrigation waters, and the rice plant, with the object of suggesting methods for maintaining the fertility of rice soils.

1. *Food Requirements of Rice.*—An average Texas rice crop consumes, on an average, 16 pounds phosphoric acid, 42 pounds nitrogen, and 55 pounds of potash, these being the more important forms of plant food.

Rice straw carries with it, when removed, 3 pounds phosphoric acid, 14 pounds nitrogen, and 31 pounds of potash per acre, having a valuation of $4.30.

In burning rice stubble nearly 5 pounds nitrogen goes up in smoke, valued at 75 cents per acre, and requiring the application of about 70 pounds of cottonseed meal to restore the loss. In burning rice straw, 14 pounds nitrogen per acre passes off, on an average, valued at $2.27, and being the amount contained in about 200 pounds cottonseed meal. The ashes contain 3 pounds phosphoric acid and 37 pounds potash per acre, with a value of $2.03. They should be scattered over the field from whence they came, to avoid this loss.

An average crop of rice consumes more nitrogen than an average crop of cotton, oats, or corn. If the rice straw is taken entirely away, the draft on the potash is four times as much as by cotton, oats, or corn. If the rice straw ashes are restored, the loss of potash is 5 pounds per acre, about half as much as is removed by cotton, oats, or corn.

2. *Irrigation Waters.*—On an average, 7.6 pounds phosphoric acid, 1.4 pounds nitrogen, and 23.4 pounds potash per acre are brought on the field by the irrigation water. This is not as much phosphoric acid, nitrogen, or potash as is consumed by a crop of rice.

It is estimated that the seepage and off-flow waters carry off approximately 4.5 pounds phosphoric acid, 3.4 pounds potash, and probably larger amounts of nitrogen.

The net result of the irrigation waters is thus an average gain of 3.1 pounds phosphoric acid and 20.0 pounds potash per acre, and a loss of nitrogen. A loss of approximately 20 pounds nitrogen per acre by percolation during the winter may take place, with small amounts of potash and phosphoric acid.

The soil loses, in the growth of an irrigated rice crop, on an average of 12 pounds phosphoric acid, 60 pounds of nitrogen, and 22 pounds potash per acre, if the straw is removed and the stubble burned. If, however, the stubble is ploughed under, and the straw ashes returned to the field they come from, there is an average loss of 9 pounds phosphoric acid, 57 pounds nitrogen, and apparently a gain of 15 pounds of potash.

3. *Composition of Soil.*—Only a limited number of soils were examined. A plant food supplied by the soil to a plant depends upon other conditions in addition to its chemical composition. If all the plant food in the soils examined could be utilized, the amount present is sufficient for the following numbers of rice crops, according to whether the straw is entirely removed or the ashes are returned.

	Entirely removed.	Ashes returned.
Phosphoric acid	40 to 75 crops	55 to 100 crops.
Nitrogen	40 to 120 crops	40 to 120 crops.
Potash	90 to 600 crops	An indefinite number.

Compared with soils of high fertility, the soil samples examined from Jefferson, Orange, DeWitt, Victoria, and the black soils of Brazoria contain small quantities of phosphoric acid. The soils from Harris county, the Rio Grande valley and the red Brazos bottom soils of Brazoria county (quoted from the Tenth U. S. Census), contain an abundance of phosphoric acid.

The Orange county soil is low in potash; the others contain a moderate amount. The Rio Grande valley soil is very rich in potash.

The Orange county soil is low in lime; the other soils contain a sufficient quantity.

According to Loew, an unfavorable ratio of lime to magnesia affects the yield. The Brownsville and DeWitt soils have an unfavorable ratio. The Brazoria, Orange, and Jefferson soils are acid. The Brazos river carries enough carbonate of lime to neutralize the acidity of the Brazoria soil in a year, but the Neches river or Cow Bayou would require eight or sixteen years, respectively. Rice is probably not affected by acidity as much as other crops. Moderate liming is a benefit on Japanese soils, but since lime decreases the availability of phosphoric acid, it must be tested on these soils before a statement can be made as to its value.

Soils may contain large quantities of plant food and yet fail to produce good crops, since the food may not be in forms that can be taken up by plants.

The Orange and Brazoria soils are deficient in phosphoric acid for nitrification; the Jefferson and DeWitt soils are not; Orange, Brazoria, and Jefferson soils are deficient in phosphoric acid for cotton, according to pot tests, but not for potash.

All soils so examined (Brazoria, Jefferson, Orange, and DeWitt) contain very small quantities of chemically available phosphoric acid measured by N/5 nitric acid. The chemically available potash measured in the same way is low in the Brazoria and Orange soils; moderate in the others.

4. *Treatment of Rice Soils.*—Burning the straw is wasteful, but if burned, the ashes should be scattered on the field from whence they came. The stubble should be ploughed under if possible. The nitrogen content of the soil should be maintained by growing leguminous crops (cowpeas, vetch, etc.), which is ploughed under, with caution, grazed off or made into hay. These plants take nitrogen from the air, while rice, cotton, etc., can not do so. The leguminous crop can be grown in rotation with rice, during a season, in which case it will have the effect of destroying water weeds and red rice (properly carried out). Or a winter growing plant may be planted in the fall and ploughed under in the spring.

Using fertilizers to supply nitrogen for rice may prove profitable until the nitrogen of the soil falls below certain limits; to secure nitrogen for rice, leguminous plants must be used sooner or later.

Phosphoric acid is probably deficient in the Orange, Jefferson, Brazoria, and Victoria soils examined. The trial of 100 pounds acid phosphate per acre is suggested.

The relative values of different sources of phosphoric acid are discussed from Japanese experiments on rice.

Potash may be deficient in the Orange county soil. The other soils do not appear to need potash. Deficiency in potash can be restored only by use of potash fertilizers.

For best results, the vegetable matter in the soil should be maintained, by ploughing under the rice stubble and by growing leguminous crops.

Lime may be of advantage east of Houston; hardly so west of it. Lime should be tried only on a small scale at first, and always in moderate amounts.

Magnesia may be of advantage on the DeWitt and Brownsville soils. Magnesia sulphate or magnesite may be used.

The practical details of these suggestions must be worked out and probably different methods of procedure will be found adapted to different localities.